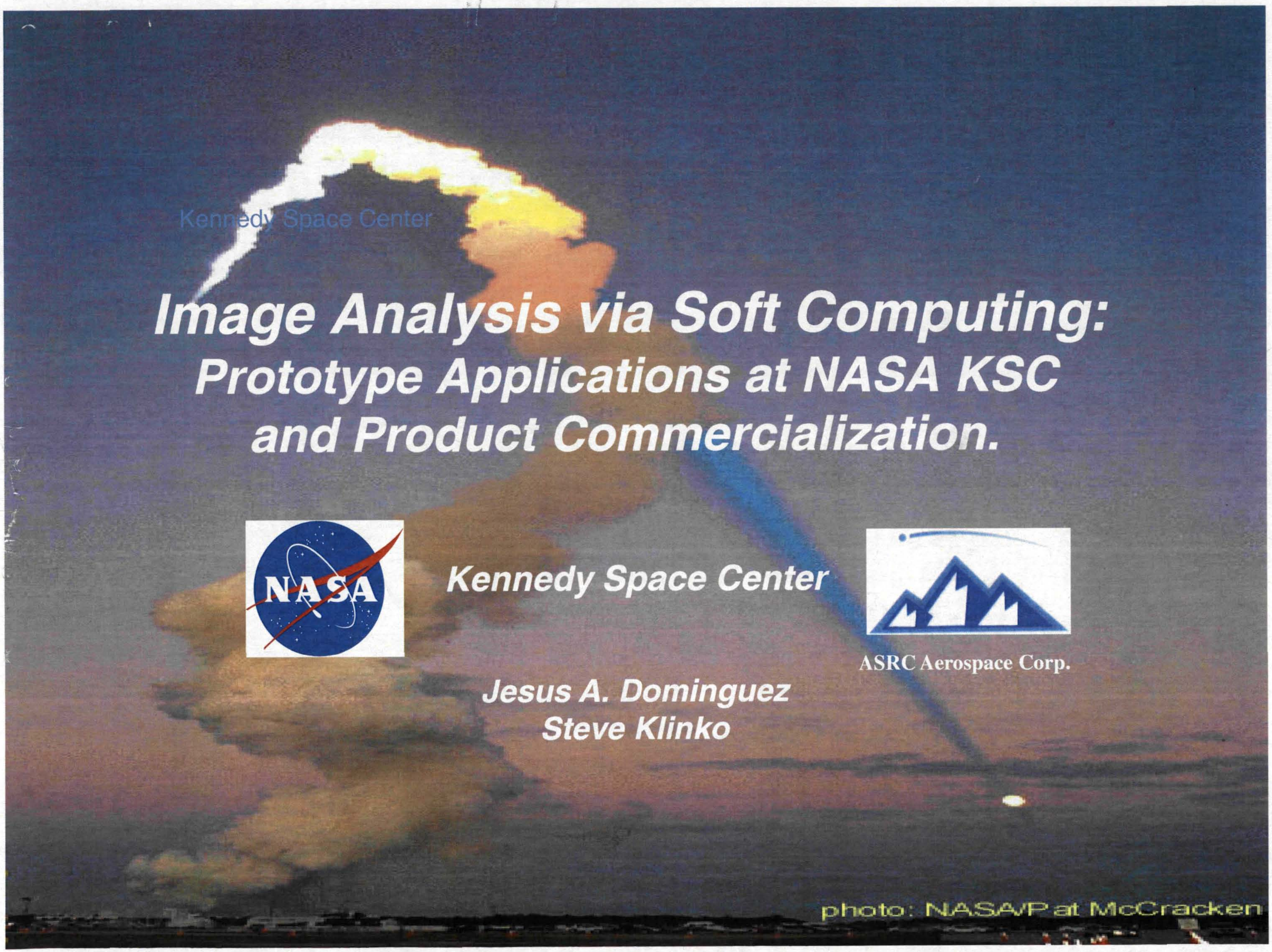


Image Analysis via Soft Computing: Prototype Applications at NASA KSC and Product Commercialization.

Kennedy Space Center

ASRC Aerospace Corp.

Jesus A. Dominguez
Steve Klinko

photo: NASA/Pat McCracken

Outline

- System Development.
- Performance results compared with existing approaches.
- NASA applications.
- Commercialization.

System Development

Soft Computing (SC):

differs from conventional (hard) computing in that, unlike hard computing, it is tolerant of imprecision, uncertainty, partial truth, and approximation.

provides flexible information processing to handle real life ambiguous situations and achieve tractability, robustness, low solution cost, and <u>close resemblance of human decision making</u>.

System Development

Kennedy Space Center

- *FRED (Fuzzy Reasoning Edge Detection):*

  Image edge extraction technique developed at KSC (patent protected).

- *FRAT (Fuzzy Reasoning Adaptive Thresholding):*

  Image binarization technique developed at KSC (patent protected).

- *Set of Image Enhancement Techniques:*

  Techniques developed at KSC (one patent protected).

- *Visual/Pattern Recognition:*

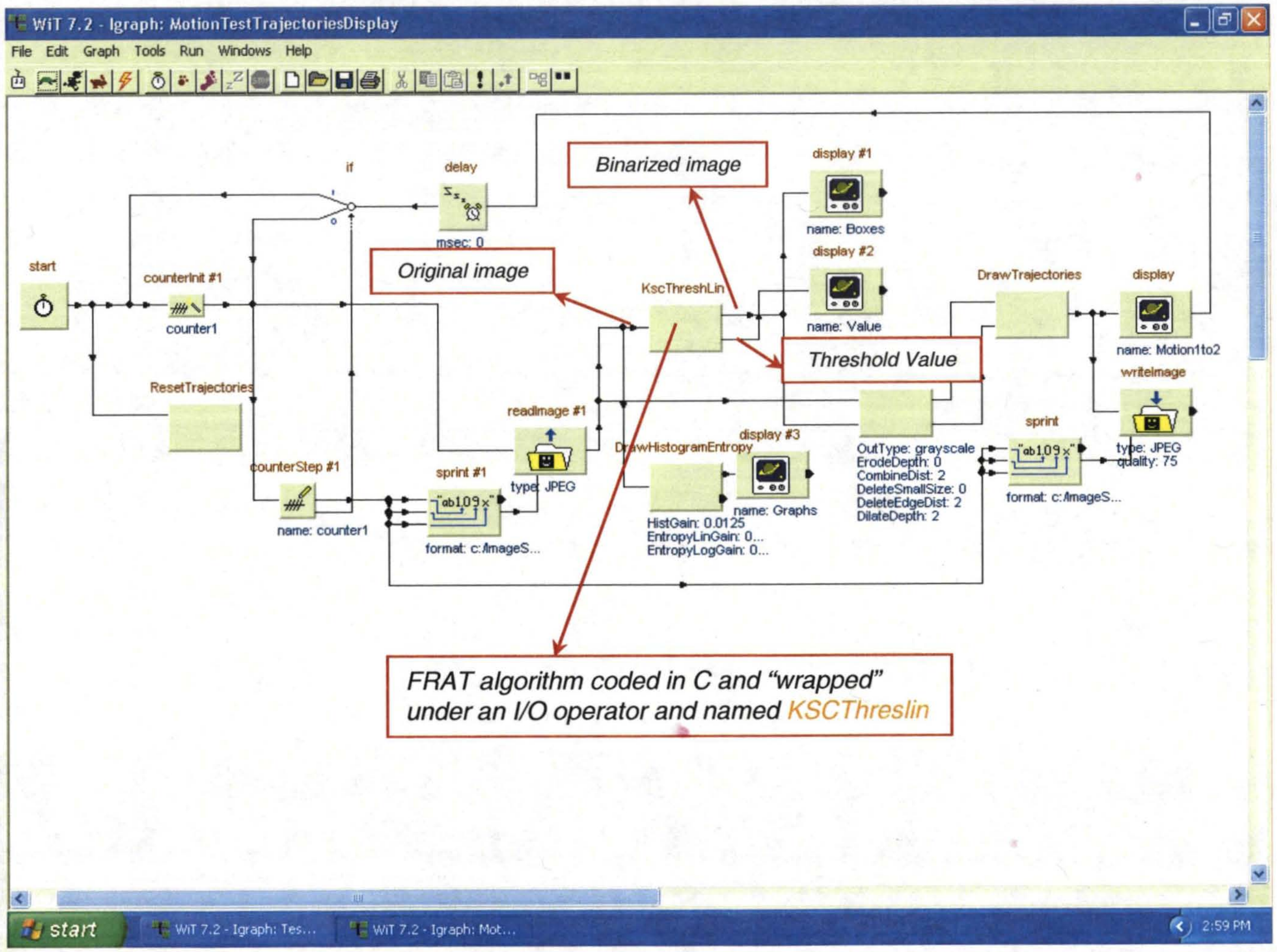
  Commercially available technique (NeuroShell) via Artificial Neural Network (ANN) and GA (Genetic Algorithm).

ASRC Aerospace Corp.

Software implementation (Cont).

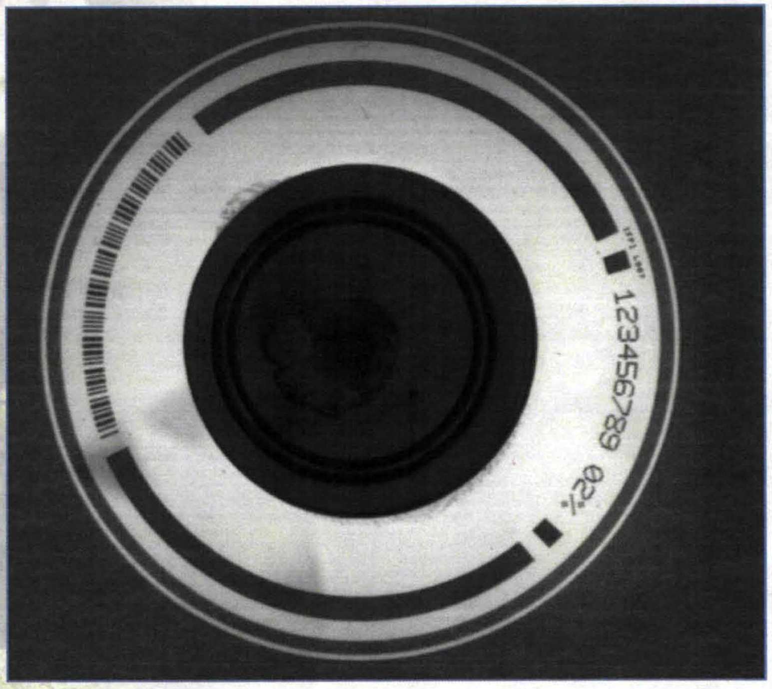
ASRC Aerospace Corp.

Kennedy Space Center

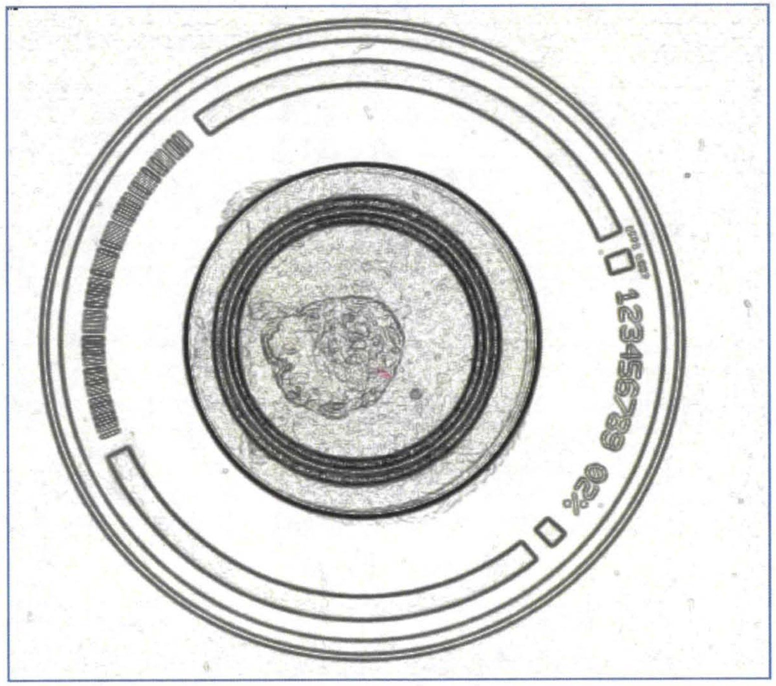


Performance results compared with existing approaches: FRED

Kennedy Space Center



Original Image: CD containing a hard-to-see major scratch on the center

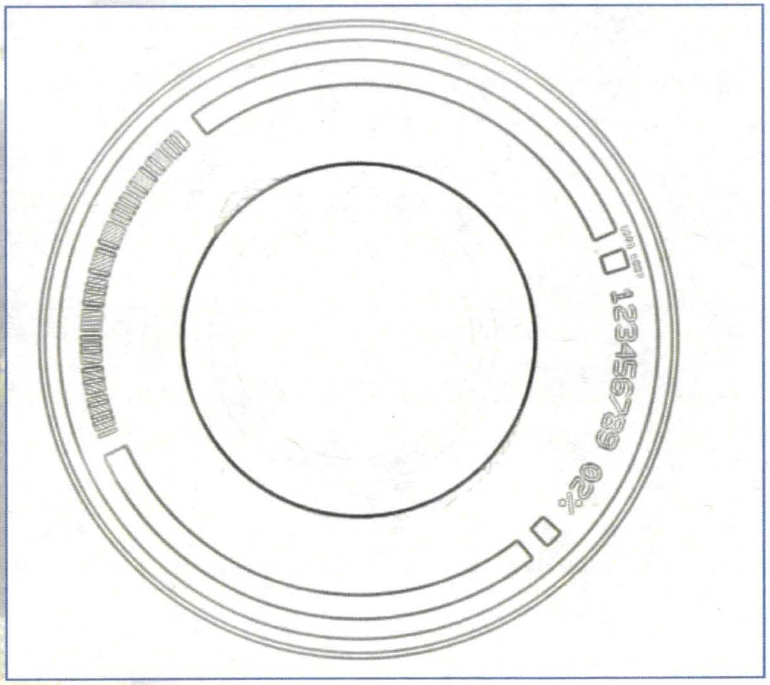


FRED: The major scratch is clearly shown as well as other minor ones

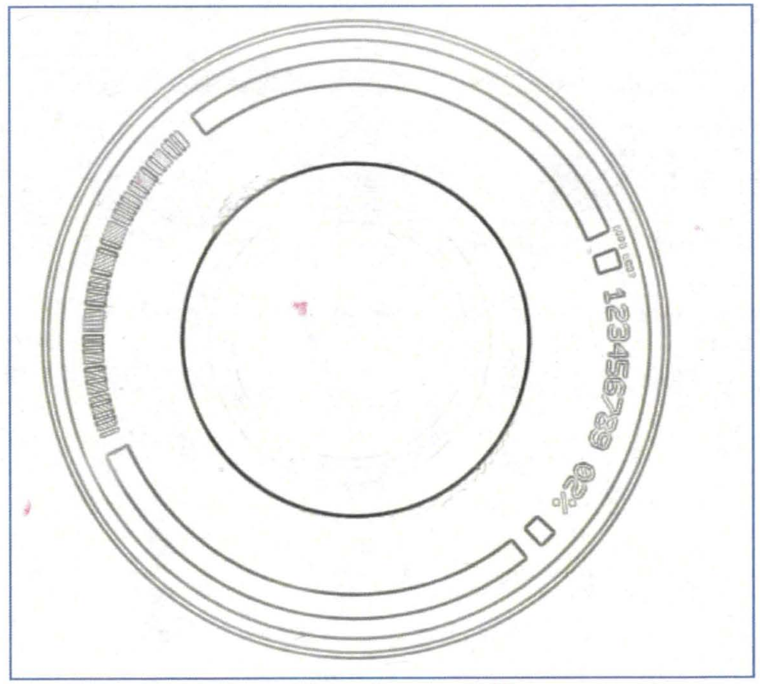
ASRC Aerospace Corp.

Performance results compared with existing approaches: FRED

Kennedy Space Center



Sobel Approach: *less clear features, major scratch invisible*



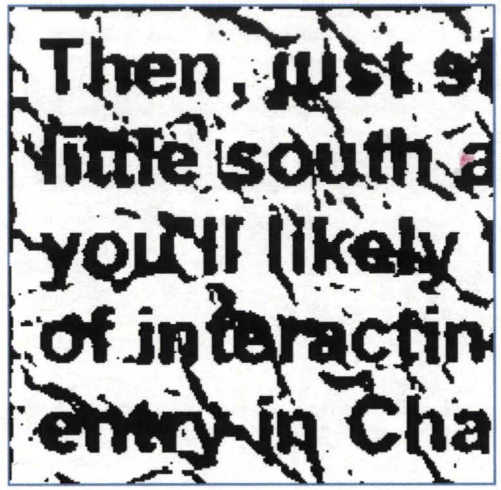
Prewit Approach: *less clear features, major scratch invisible*

ASRC Aerospace Corp.

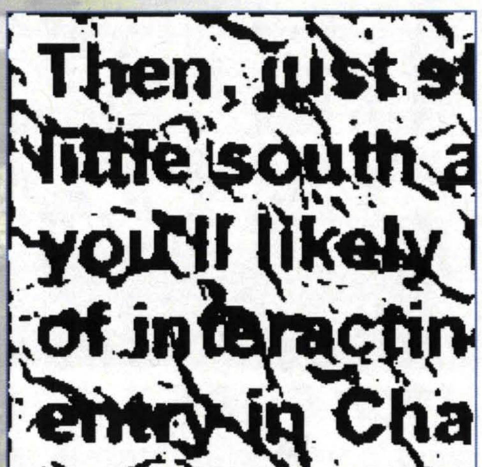
Kennedy Space Center

Performance results compared with existing approaches: FRAT

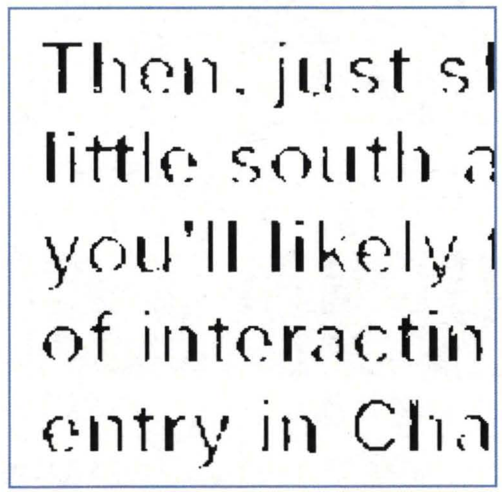
Original 8-bit Image
Size: 246×245



Otsu's Method
CPU time: 1.5 ms
Threshold: 88



Huang-Wang Method
CPU time: 10.8 ms
Threshold: 89



New Method
CPU time: 2.0 ms
Threshold: 8

ASRC Aerospace Corp.

NASA Applications

- *Real-Time (RT) Anomaly Detection.*
- *Real-Time (RT) Moving Debris Detection.*
- *Columbia Investigation.*

RT Anomaly Detection

- *Image Preprocessing*.
  Enhancement
  Segmentation (Binarization)

FRAT

- *Classification and Learning Processes*.
  Artificial Neural Network (ANN)
  Genetic Algorithm (GA).

RT Anomaly Detection

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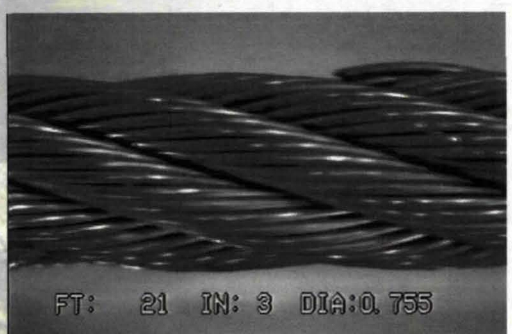
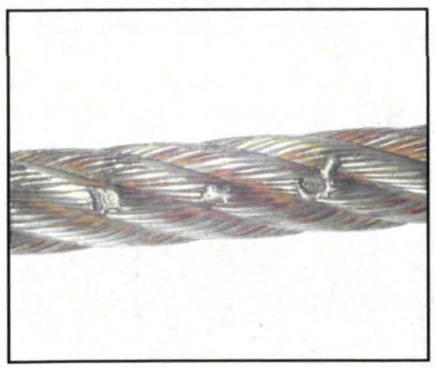
Kennedy Space Center

Astronauts training on the emergency egress system.

Anomalies on the basket slidewire





Broken strand.

Molten spots caused by lighting.

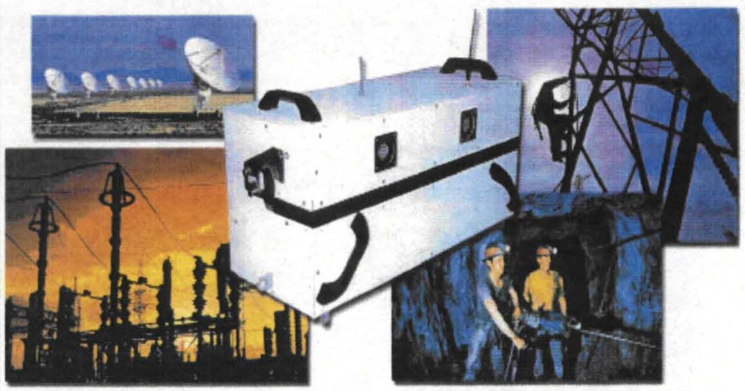
RT Anomaly Detection (Cont.)

ASRC Aerospace Corp.

Kennedy Space Center

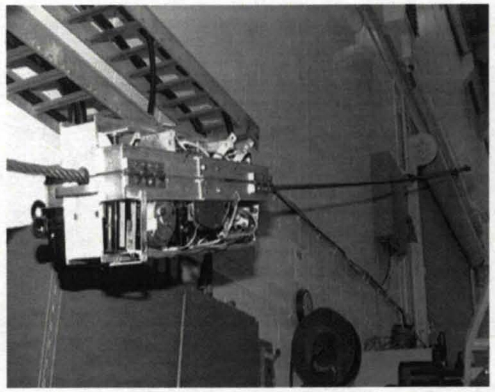
Cable and Line Inspection Mechanism (CLIM)

The National Aeronautics and Space Administration (NASA) seeks to transfer the NASA-developed Cable and Line Inspection Mechanism technology to private industry for use in commercial applications. This mechanism was developed at the John F. Kennedy Space Center (KSC) to provide a means for automated inspection of the seven slidewire cables used in the emergency egress system for the Space Shuttle. There are two sets of gantry cables plus an overhead lightning cable that require periodic inspection. These cables are nonferrous stainless steel; therefore, magnetic cable testers are not suitable for such inspections. Prior to this invention, cable inspections required 150 man-hours twice per year, with inspectors being hoisted in baskets to manually inspect the cables by direct touch and sight. The CLIM technology eliminates the hazardous, manpower-intensive, and time-consuming methods previously required to maintain the emergency egress system at peak performance standards. In addition, CLIM is capable of inspecting the top end of ferrous wire ropes near the attachment point in the cable housing where magnetic cable testers are unable to reach. CLIM has a further application with respect to radio frequency (RF) tower guy-wire inspections. The low-carbon, low-magnetic inductance of the stainless-steel guy-wire cables, combined with added RF radiation interference from the tower, yields magnetic cable testers ineffective. Therefore, CLIM's ability to conduct a 360-degree view of the cable without incurring RF radiation interference is significant.

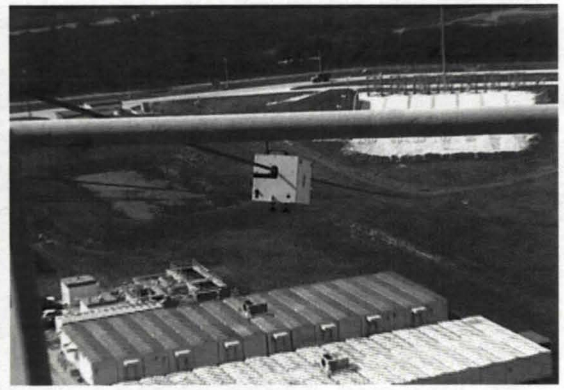


National Aeronautics and Space Administration
John F. Kennedy Space Center, FL

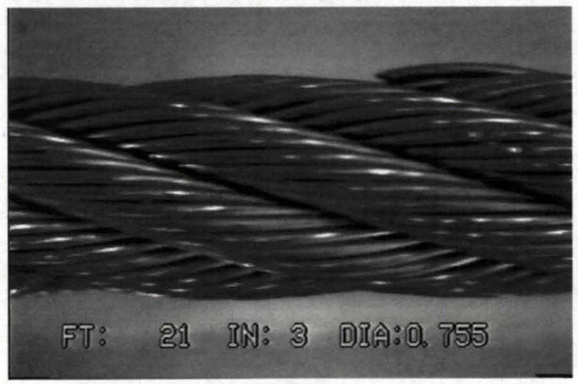
Cable & Line Inspection Mechanism (CLIM) built by NASA.



CLIM at the lab.



CLIM at the Shuttle Pad



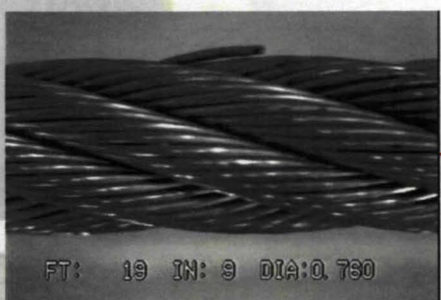
Slidewire image acquired by CLIM

RT Anomaly Detection (Cont.)

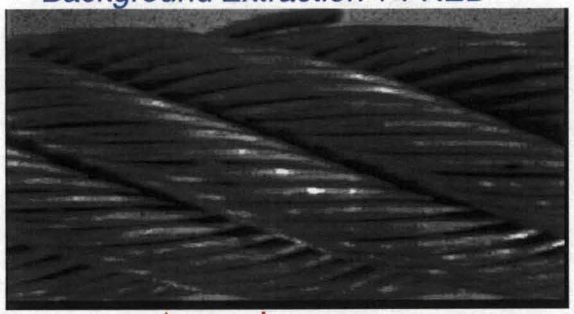
ASRC Aerospace Corp.

Kennedy Space Center

Original

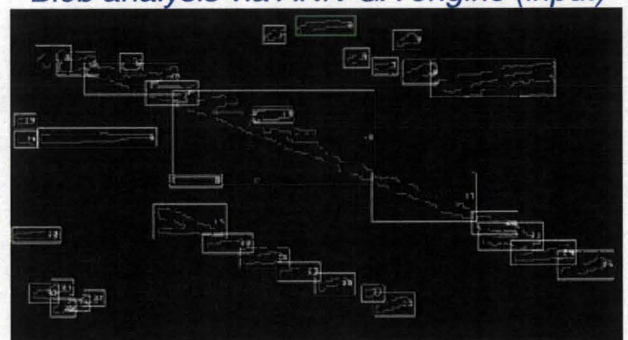


Background Extraction + FRED

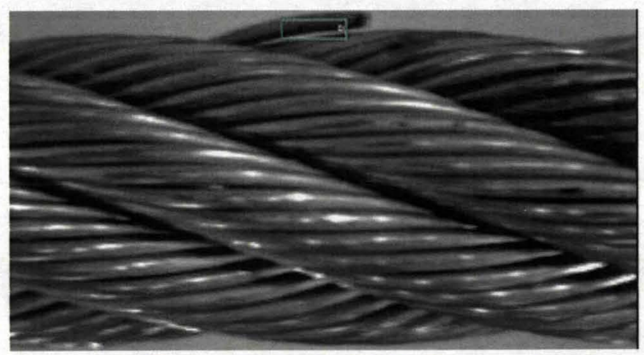


Binarization via FRAT

Blob analysis via ANN-GA engine (input)



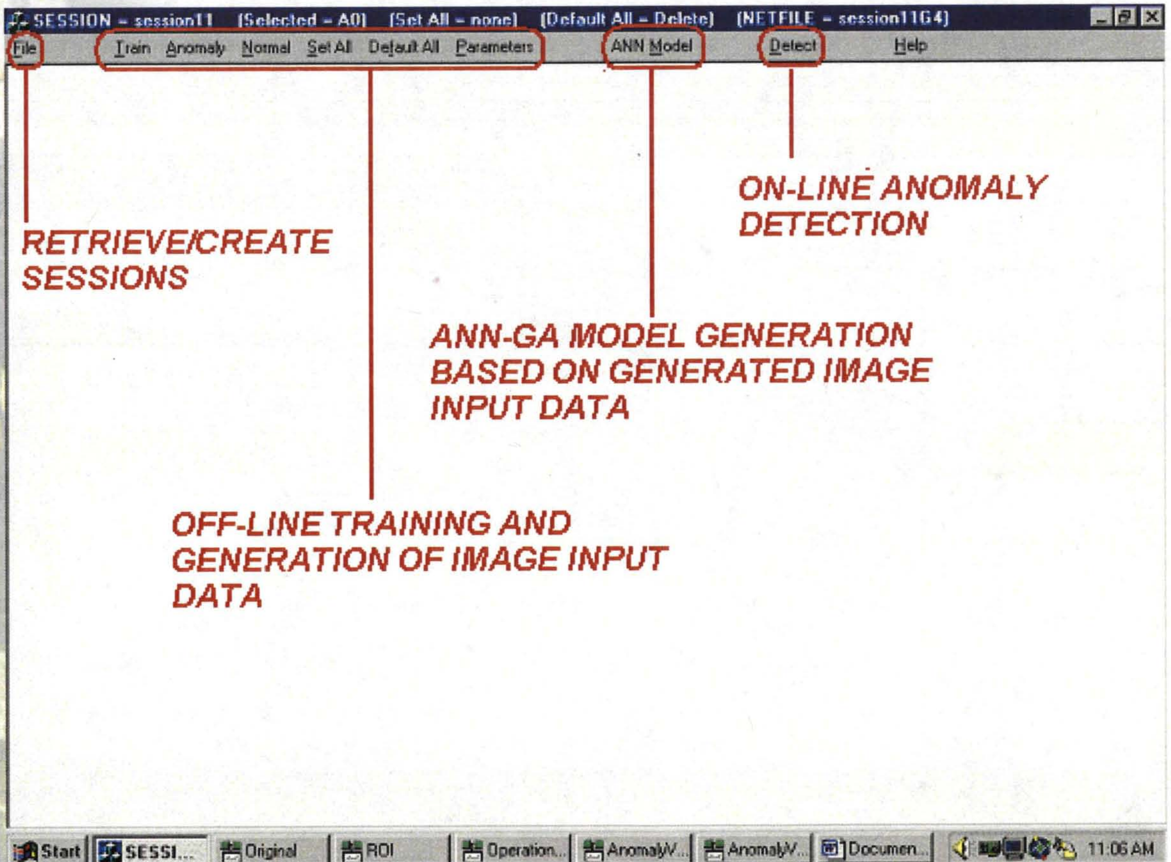
Anomaly Detection via ANN-GA engine (output)



RT Anomaly Detection (Cont.)

ASRC Aerospace Corp.

Kennedy Space Center



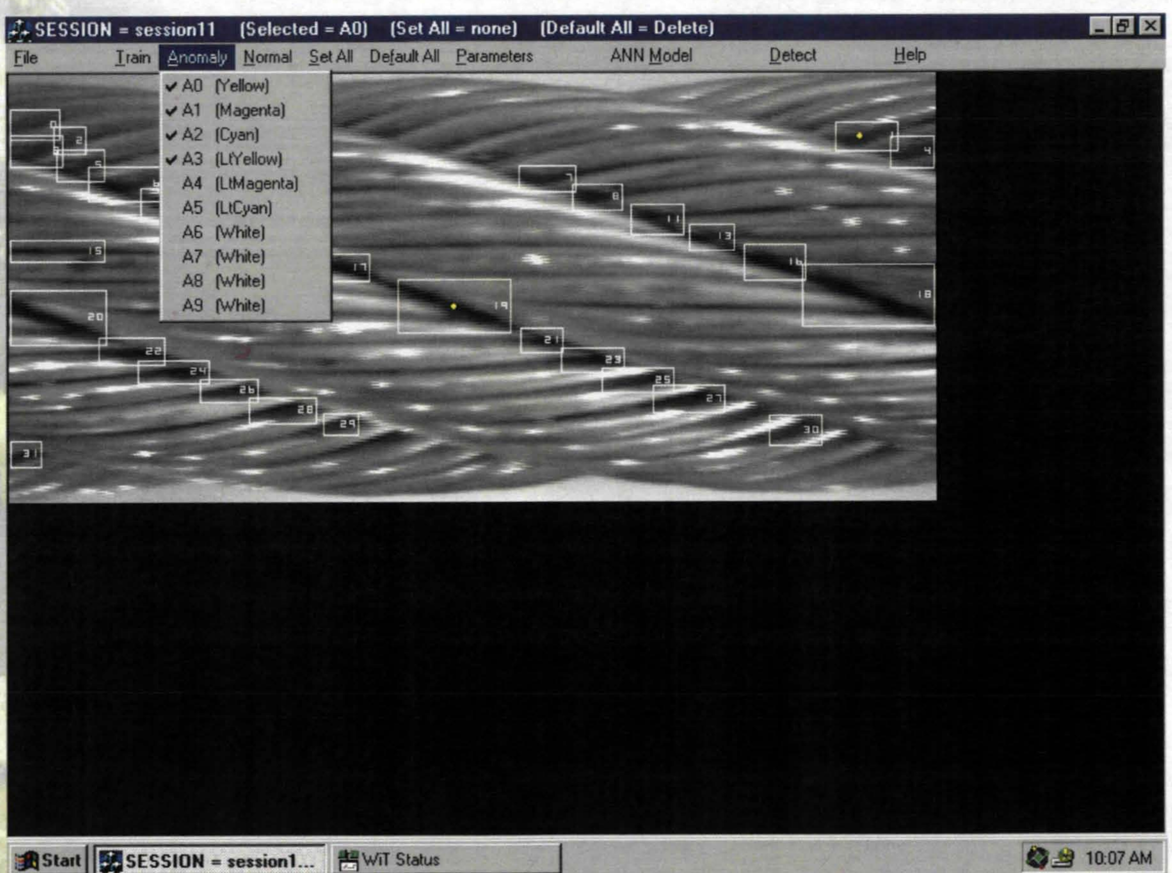
End-user front end built via MFC.

Main Menu

RT Anomaly Detection (Cont.)

Kennedy Space Center

ASRC Aerospace Corp.



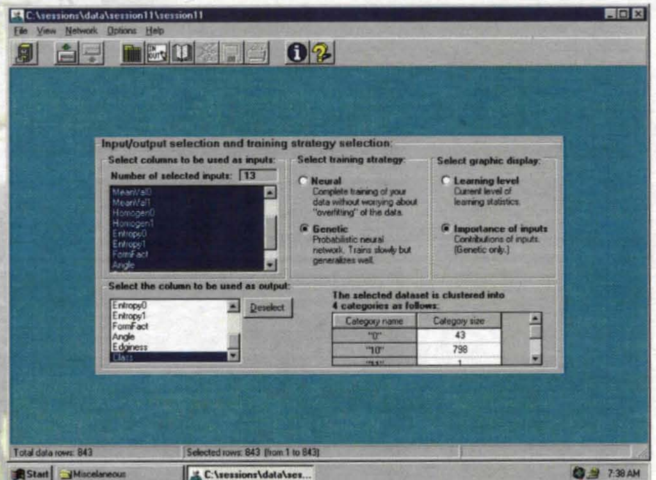
End-user front end built via MFC.

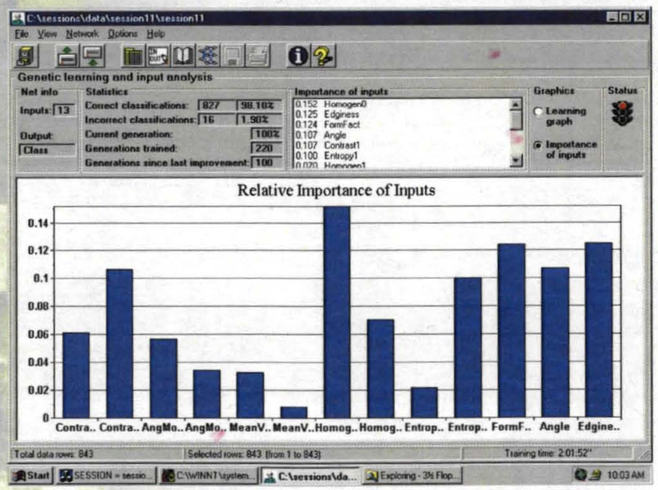
Training Stage.

RT Anomaly Detection (Cont.)

ASRC Aerospace Corp.

Kennedy Space Center





NeuroShell Classifier - Trained Network Information

Network filename: C:\sessions\data\session11\session11G3.net

The network was trained on:

Filename:	C:\sessions\data\session11\session11.dat
Total data rows:	798
Training rows:	798
Start row:	1
End row:	798

Results of training session:

Training time:	1:20:16"
Generations trained:	178
Correct classifications:	98.87% (789 of 798)
Incorrect classifications:	1.13% (9 of 798)

Performance by category:

"0"	90.48% (38 of 42)
"10"	99.34% (751 of 756)

Network structure:

Training strategy:	Genetic
Output name:	"Class"
Number of inputs:	13

List of inputs and their relative importance:

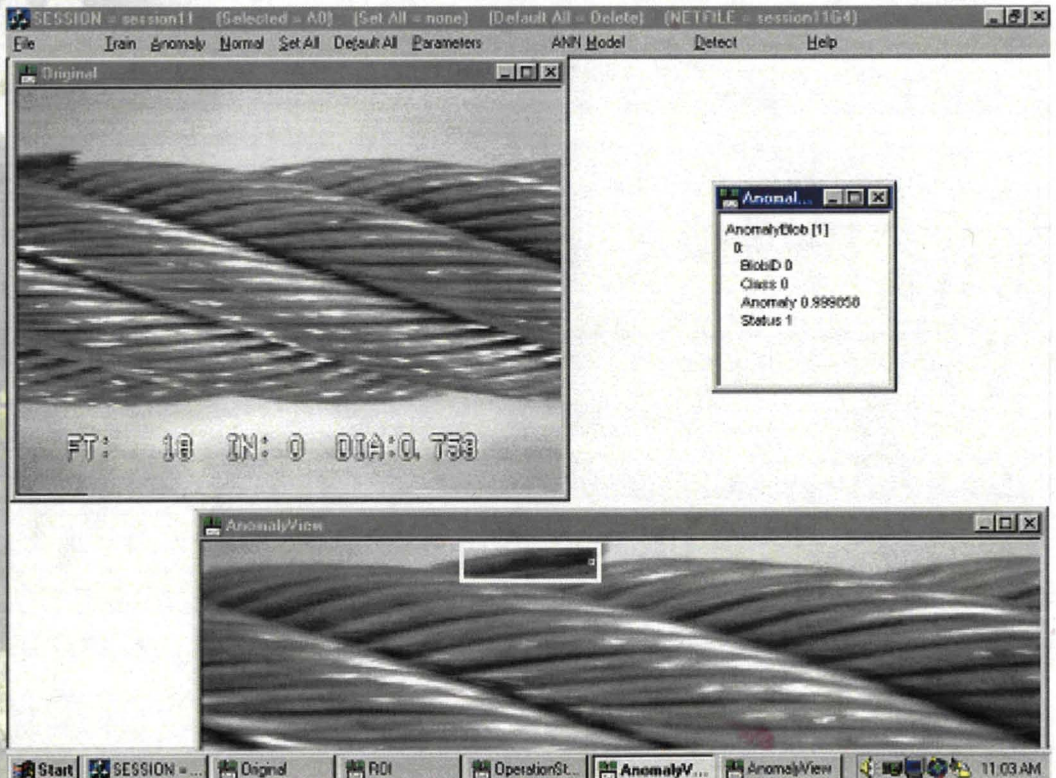
"Contrast0"	0.006
"Contrast1"	0.163
"AngMom20"	0.074
"AngMom21"	0.018
"MeanVal0"	0.018
"MeanVal1"	0.074
"Homogen0"	0.095
"Homogen1"	0.045
"Entropy0"	0.184
"Entropy1"	0.01
"FormFact"	0.094
"Angle"	0.115
"Edginess"	0.106

Development of classification model via ANN & GA (NeuroShell)

RT Anomaly Detection (Cont.)

ASRC Aerospace Corp.

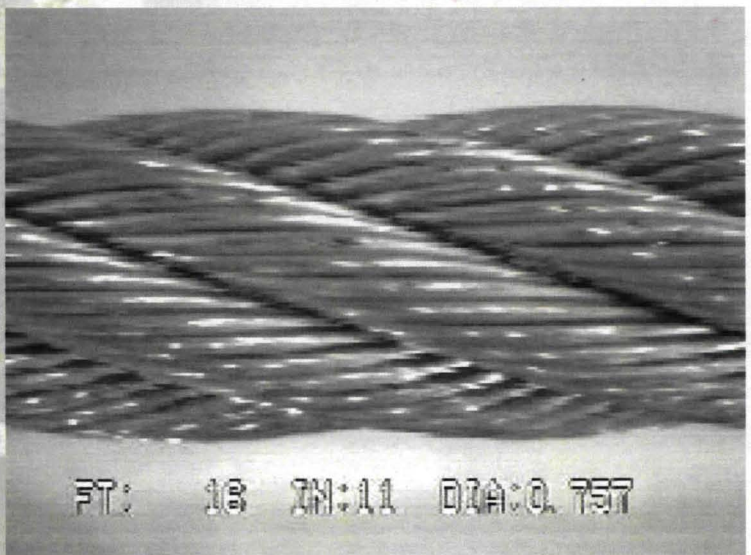
Kennedy Space Center



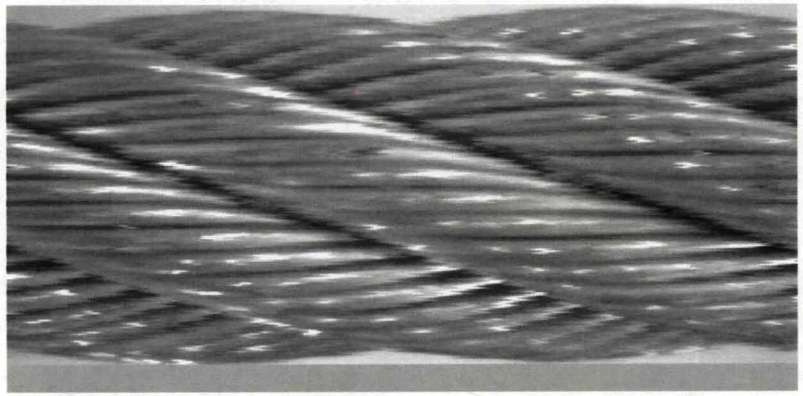
Anomaly Detected & displayed in RT.

Firing stage

RT Anomaly Detection (Cont.)



Original image acquired by CLIM



Automated Region of Interest (ROI) extraction and anomaly detection.

RT Moving FOD Detection

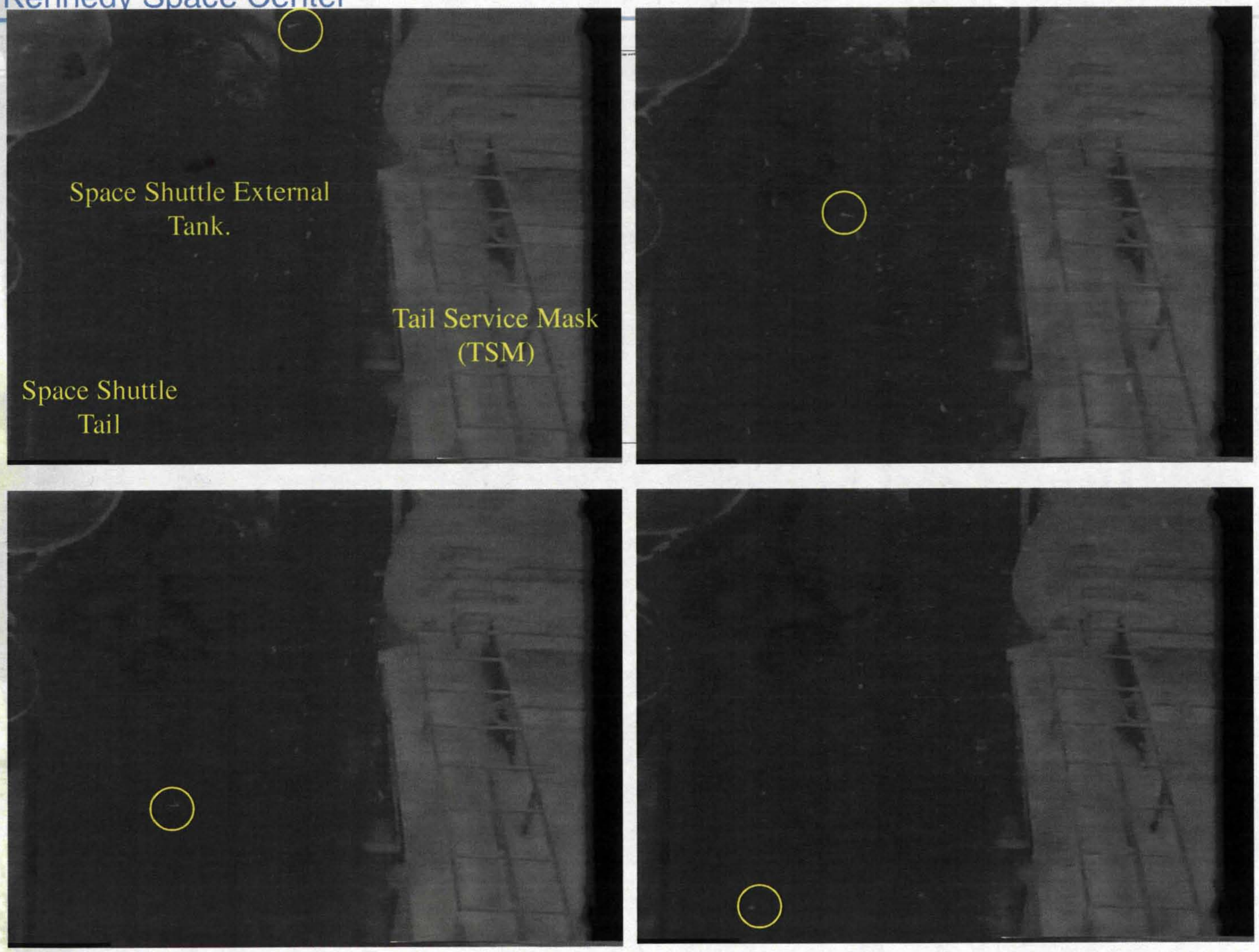
FRAT

- Blob Generation (single image).
  Segmentation (Binarization)
- Blob/FOD Selection and Trajectory Computation
  Logical path analysis (consecutive images).

RT Moving FOD Detection (Cont.)

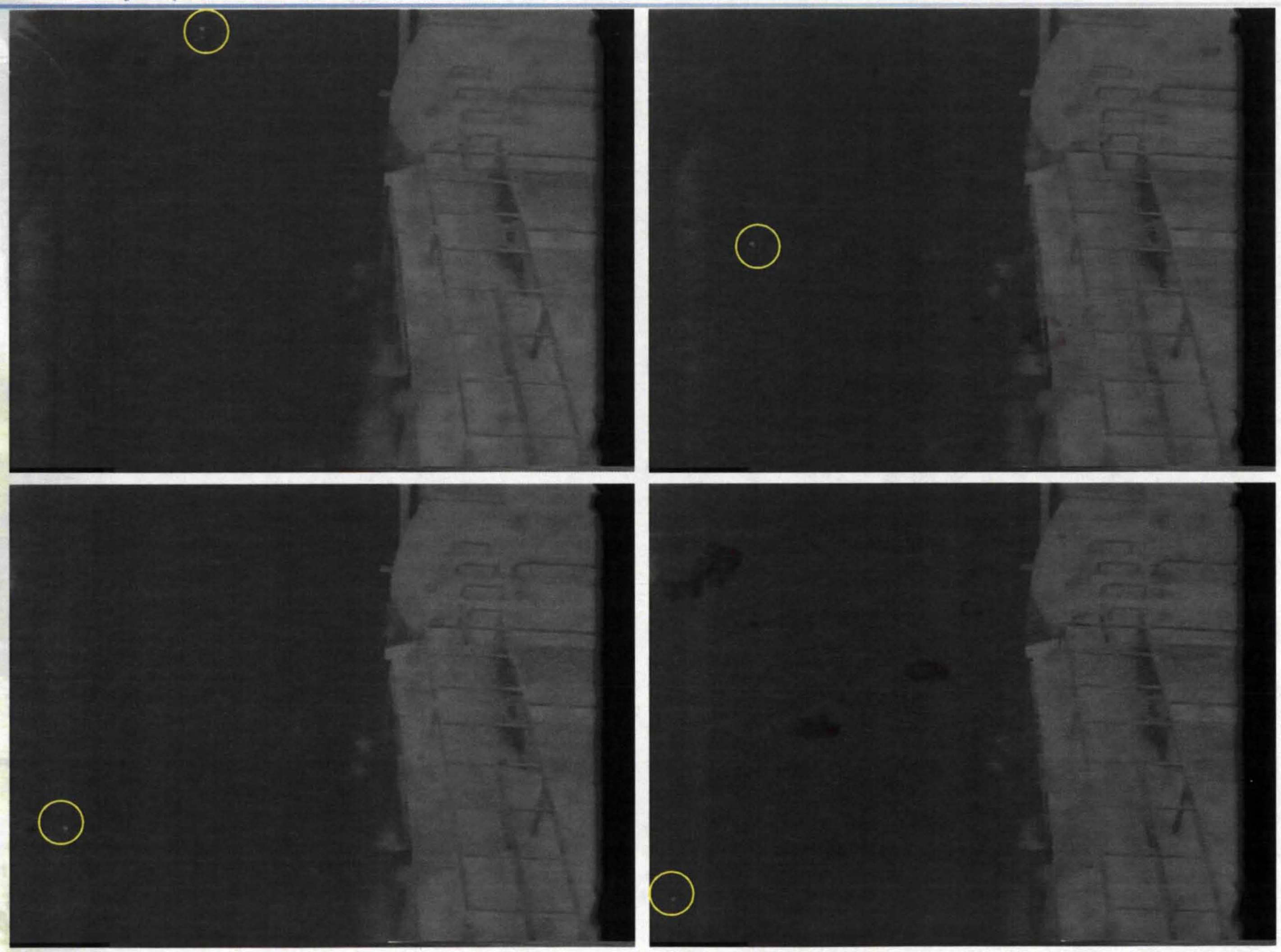
ASRC Aerospace Corp.

Kennedy Space Center



RT Moving FOD Detection (Cont.)

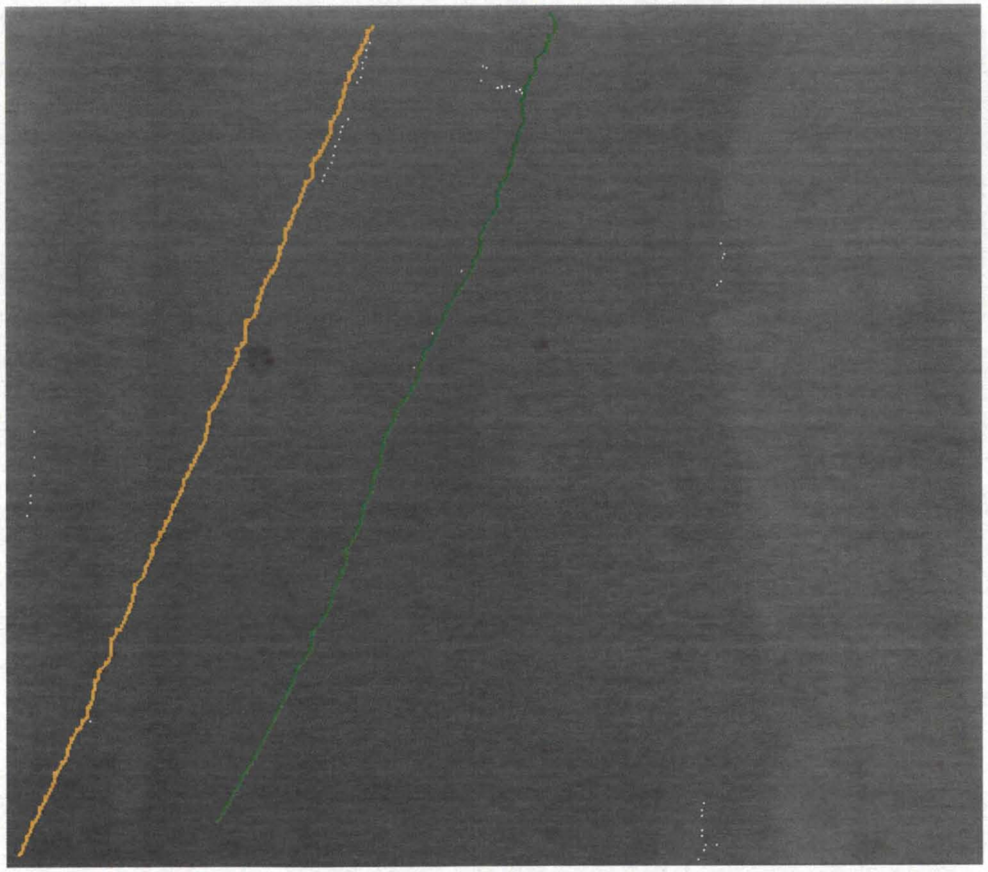
Kennedy Space Center



RT Moving FOD Detection (Cont.)

ASRC Aerospace Corp.

Kennedy Space Center



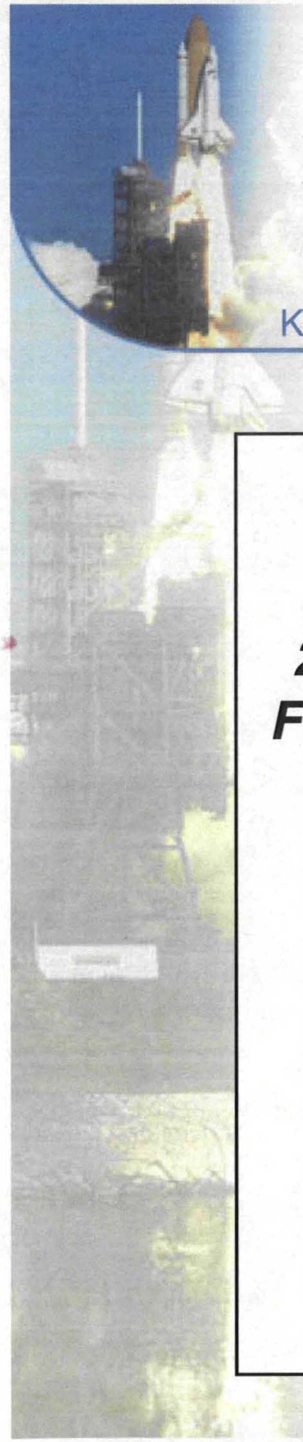
Columbia Investigation

ASRC Aerospace Corp.

Foam Debris

- 2D: Detection & Location.
  Segmentation (Binarization) FRAT
  Characterization (center of mass, borders, etc.)

- 3D: Location & Trajectory
  Optimal path at three consecutive 3D projections.



Columbia Investigation

ASRC Aerospace Corp.

Kennedy Space Center

STS-107 REPORT:

2D-Detection, 3D-Location & 3D-Velocity Estimation of Foam Debris Based on Images acquired by E212 & E208 Video Cameras.

ASRC Aerospace Corp.

Jesus A. Dominguez, ASRC Aerospace Corp.

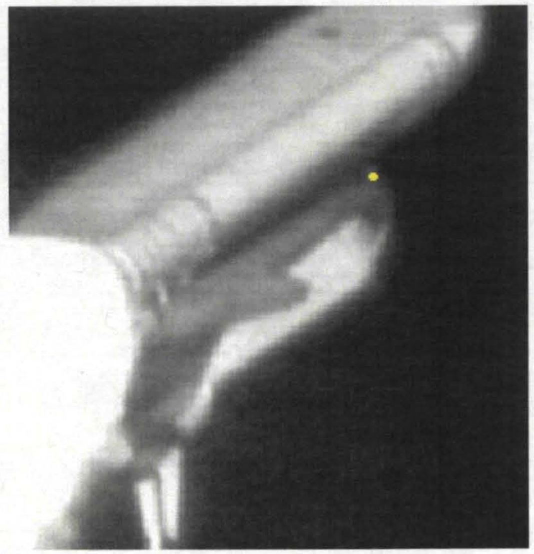
NASA Kennedy Space Center, June 12, 2003

Columbia Investigation: Foam Debris Detection/Location (Cont.)

ASRC Aerospace Corp.

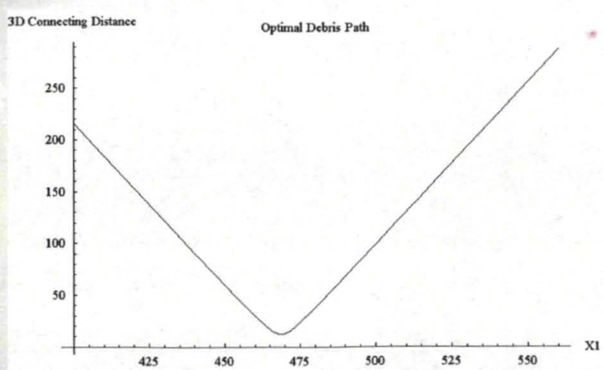
Kennedy Space Center

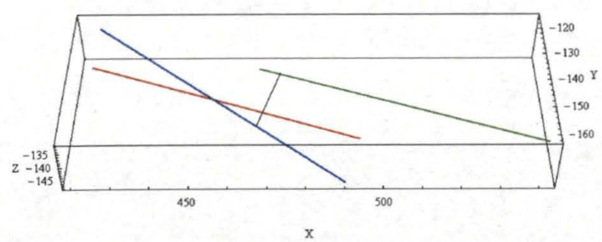
E212 at 21.753 s



ET208 at 21.757 s

E212 at 21.769 s





E212 at 21.753 s — E212 at 21.769 s

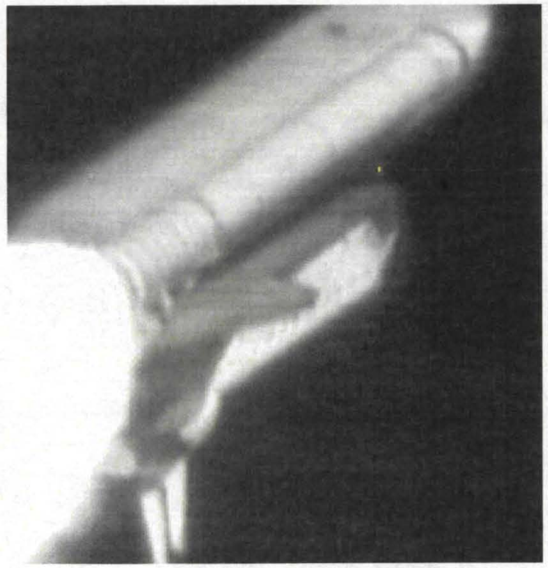
ET208 at 21.757 s — Optimized path.

Columbia Investigation: Foam Debris Detection/Location (Cont.)

ASRC Aerospace Corp.

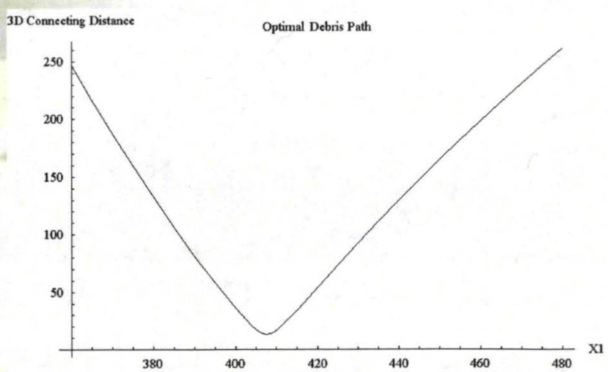
Kennedy Space Center

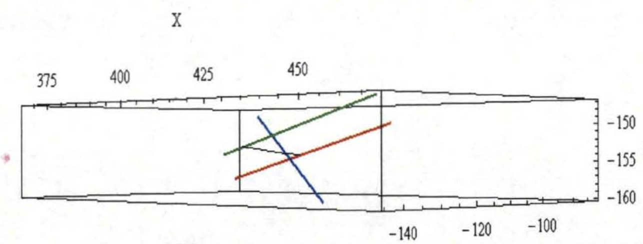
E212 at 21.722 s



ET208 at 21.724 s

E212 at 21.738 s





E212 at 21.722 s — E212 at 21.738 s

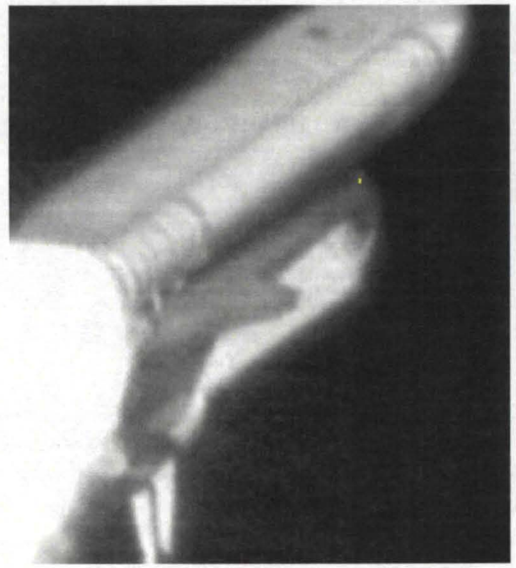
ET208 at 21.724 s — Optimized path.

Columbia Investigation: Foam Debris Detection/Location (Cont.)

ASRC Aerospace Corp.

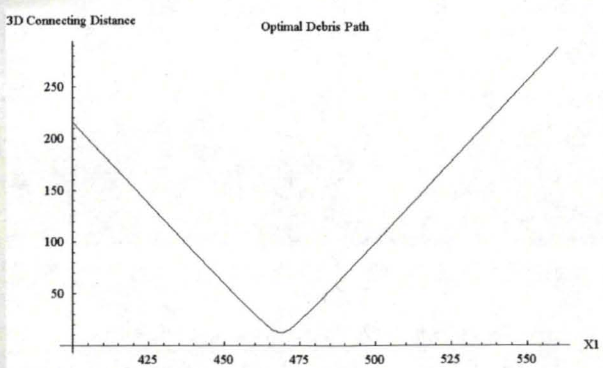
Kennedy Space Center

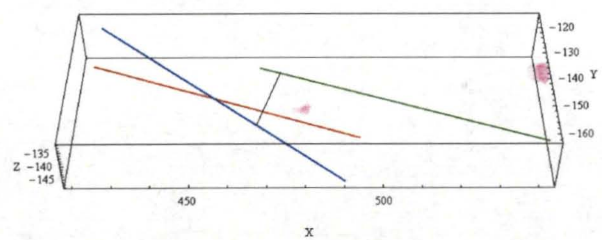
E212 at 21.753 s



ET208 at 21.757 s

E212 at 21.769 s





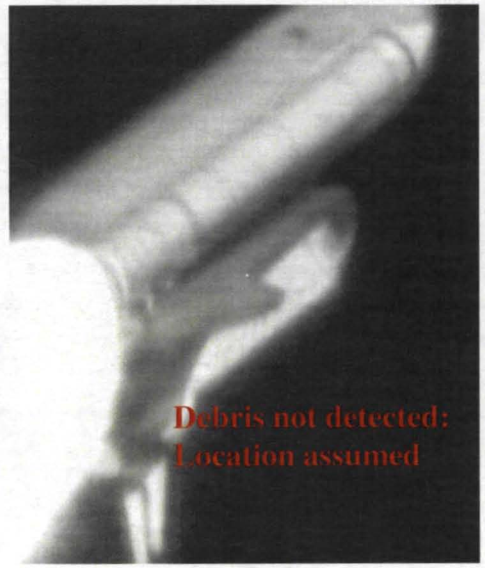
E212 at 21.753 s — E212 at 21.769 s

ET208 at 21.757 s — Optimized path.

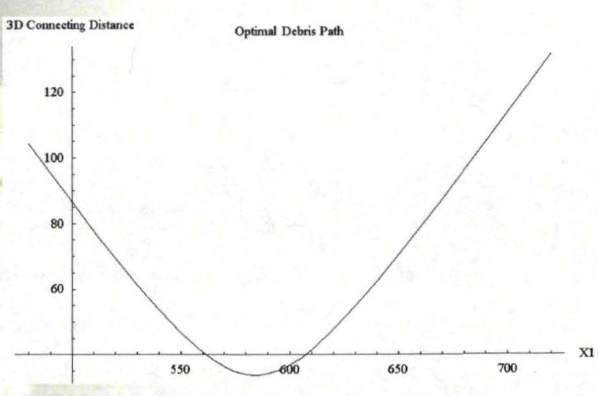
Columbia Investigation: Foam Debris Detection/Location (Cont.)

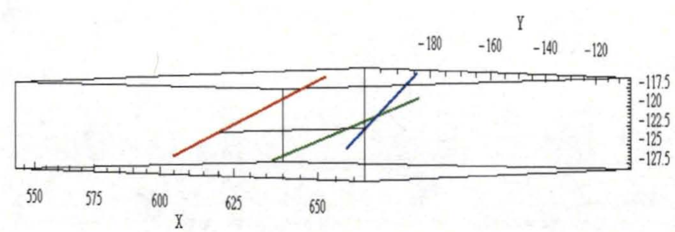
ASRC Aerospace Corp.

Kennedy Space Center



E212 at 21.784 s — ET208 at 21.791 s — E212 at 21.800 s





E212 at 21.784 s — E212 at 21.800 s

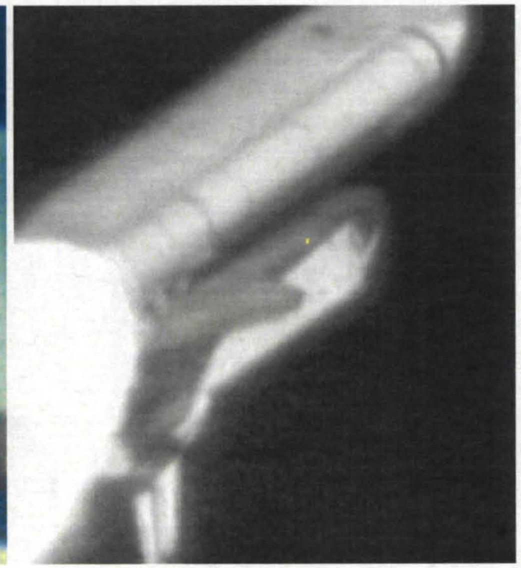
ET208 at 21.791 s — Optimized path.

Columbia Investigation: Foam Debris Detection/Location (Cont.)

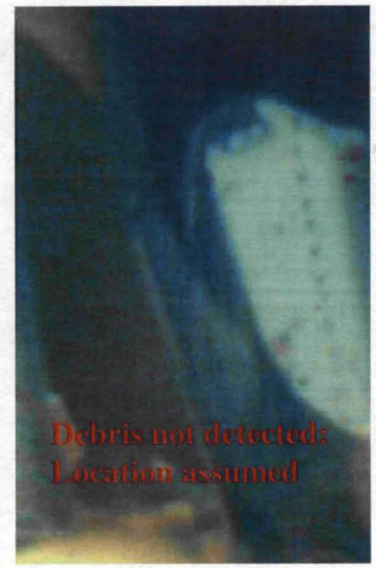
ASRC Aerospace Corp.

Kennedy Space Center

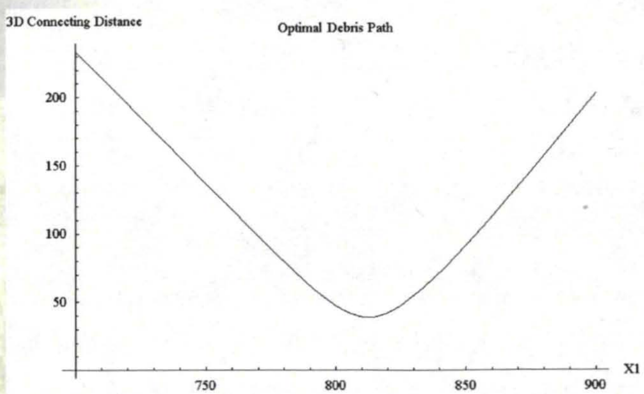
E212 at 21.816 s

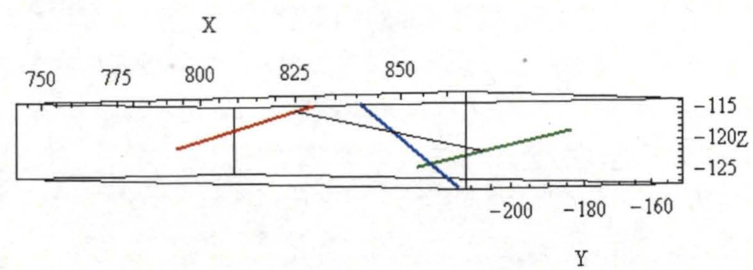


ET208 at 21.824 s



E212 at 21.831 s



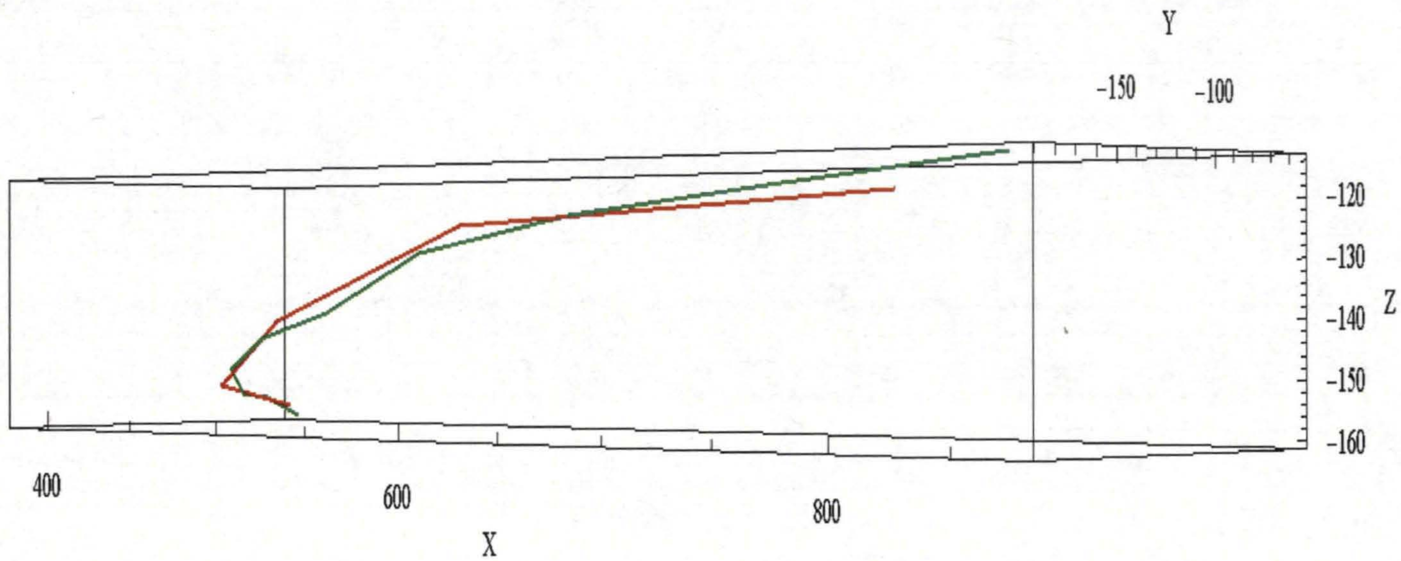


E212 at 21.816 s ***E212 at 21.831 s***

ET208 at 21.824 s ***Optimized path.***

Columbia Investigation: Foam Debris Trajectory

Kennedy Space Center

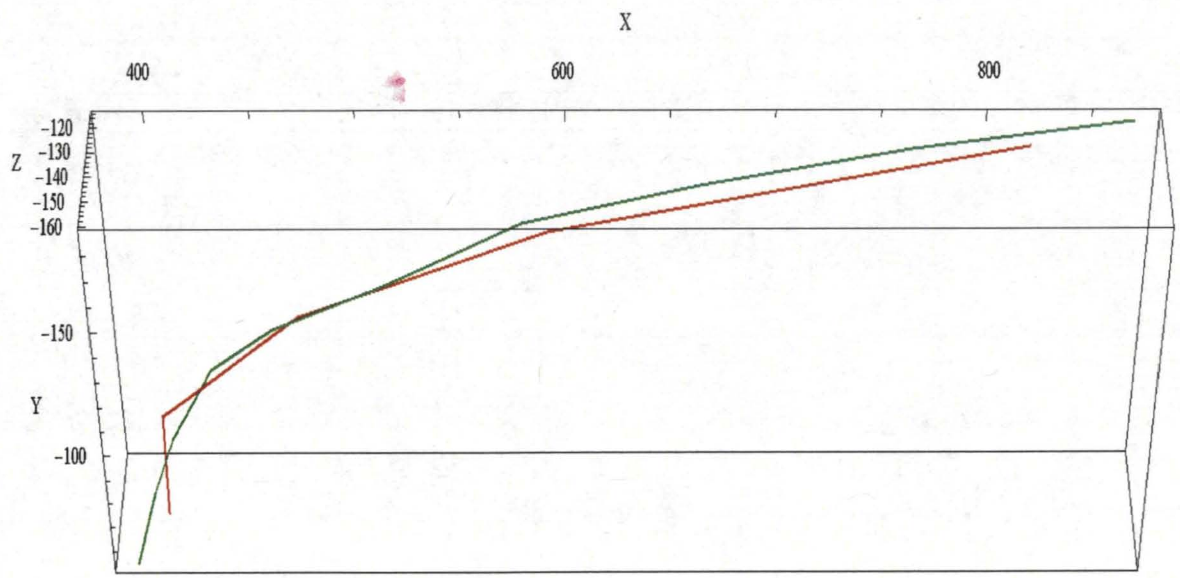


Current Work — Lane-Nelson work via LighWave3D

ASRC Aerospace Corp.

Columbia Investigation: Foam Debris Trajectory

Kennedy Space Center

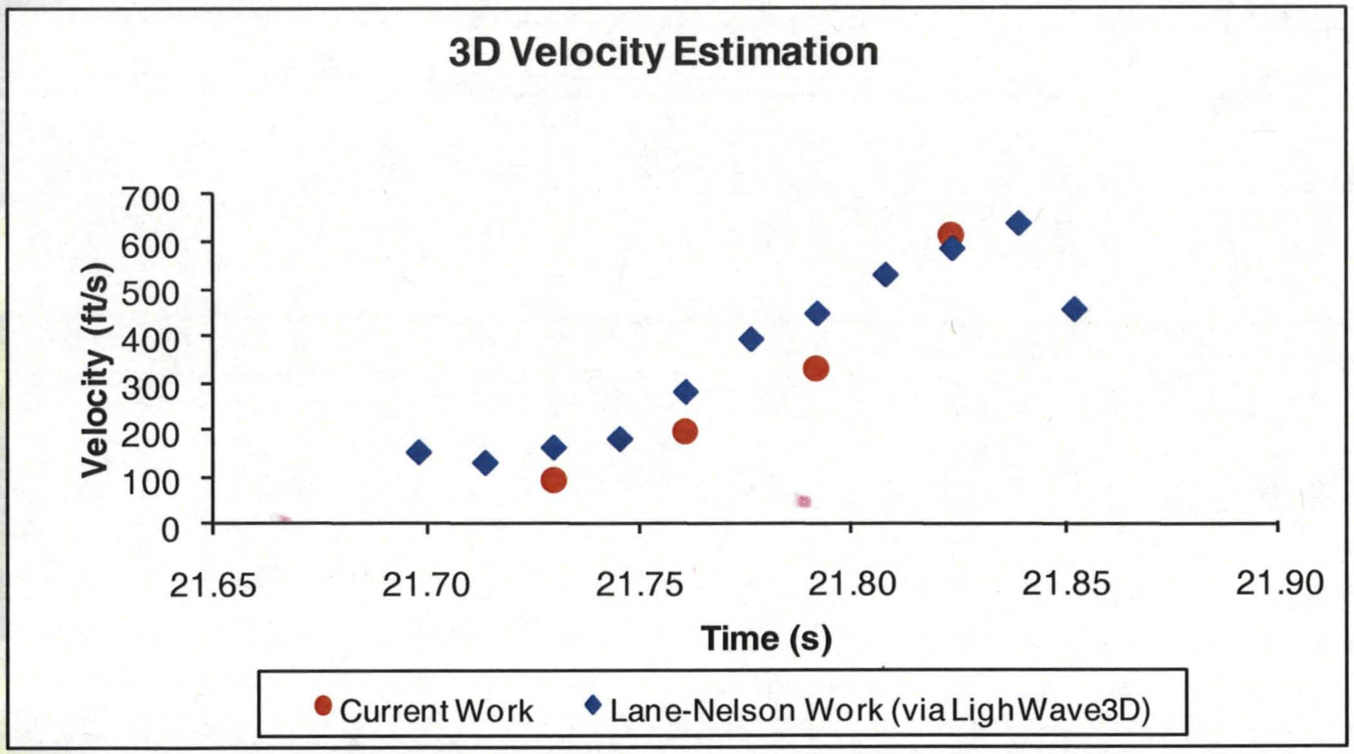


__Current Work__ *__Lane-Nelson work via LighWave3D__*

ASRC Aerospace Corp.

Columbia Investigation: Foam Debris Velocity

Kennedy Space Center



ASRC Aerospace Corp.

Proposed Debris Analysis Software System Development at KSC

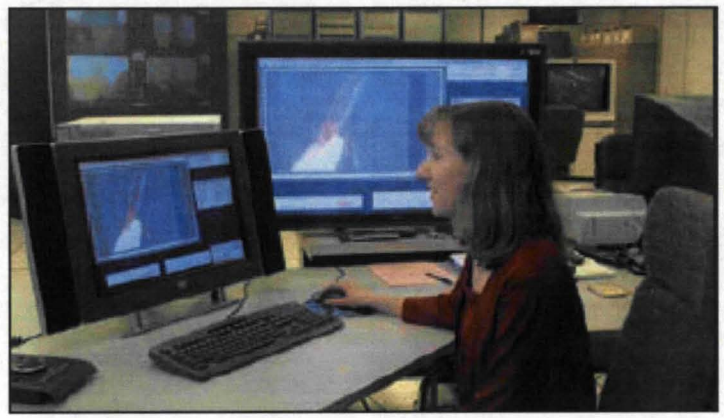
Kennedy Space Center

Automated Debris Detection at KSC VAB Launch Analysis Laboratory

sgi

Microsoft Windows

Current OS housing FRAT, FRED, SC-based image pattern recognition.



VAB Launch Analysis Laboratory at KSC equipped with recently acquired SGI Reality Center facility with a 7-foot display, and advanced SGI TP9500 data management subsystem.

ASRC Aerospace Corp.

Commercialization: Licensing

ASRC Aerospace Corp.

Kennedy Space Center

Patent

NASA KSC

Technology Marketing

RTI INTERNATIONAL

Research Triangle Institute (RTI)
Center for Technology Applications
PO Box 12194, 3040 Cornwallis
Research Triangle Park, NC 27709

NASA Technology Applications Team:

Kirsten Rieth
Phone: (919) 967-4991
Fax: (919) 541-6221
Email: krieth@rti.org

John Geikler
Phone: (919) 941-8372
Fax: (919) 941-8399
Email: johng@thesolutioncenter.com

Commercialization (Cont.)

ASRC Aerospace Corp.

Kennedy Space Center

http://nasa.rti.org/ksc/imaging

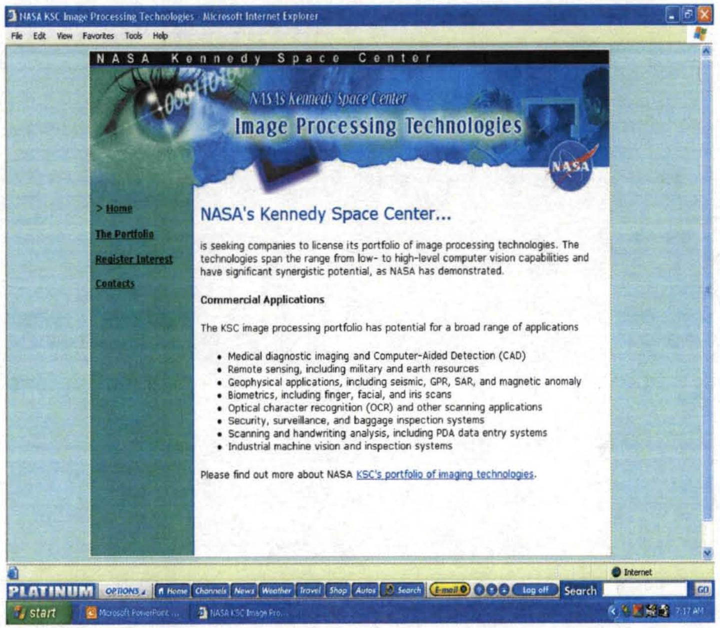


Figure 8

Commercialization (Cont.)

ASRC Aerospace Corp.

Kennedy Space Center

TECHNOLOGY *Opportunity*

IMAGE PROCESSING TECHNOLOGY

Binarization of Noisy Images

A Fuzzy Reasoning Method

NASA's Kennedy Space Center (KSC) is seeking companies to license its fuzzy reasoning adaptive thresholding (FRAT) system. Used for binarization of gray-scale images, this technology is faster and more reliable than current high-reliability methods and is especially effective in noisy environments.

Benefits

- Superior performance in noisy, cluttered, or textured images
- More reliable and significantly faster then current fuzzy reasoning approaches
- More reliable than nonfuzzy reasoning approaches and comparable in speed
- Fully developed and proven effective in a critical NASA system

Commercial Applications

Currently used to analyze launch debris and a crucial part of NASA's investigation into the Space Shuttle Columbia tragedy, FRAT has numerous potential commercial applications, including

- Medical diagnostic imaging and Computer-Aided Detection (CAD) systems
- Remote sensing, including military and earth resources
- Geophysical applications, including seismic, GPR, SAR, and magnetic anomaly
- Biometrics, including finger, facial, and iris scans
- Optical character recognition (OCR) and other scanning applications
- Security, surveillance, and baggage inspection systems
- Industrial machine vision and inspection systems

National Aeronautics and Space Administration

Technology

NASA's fuzzy reasoning adaptive thresholding (FRAT) system is ideal for binarizing noisy, cluttered, or textured gray-scale images. Using a faster computational technique that improves on previous fuzzy entropy functions, FRAT is faster and more reliable than other current, highly reliable methods.

FRAT defines an image as an array of fuzzy singletons, corresponding to image pixels. With two classes, background and foreground, the membership function is built based on the average gray level of each class, which is computed using the grey-level histogram as average weight factor.

By using an unrestricted range and a straightforward triangular-type membership function, FRAT takes advantage of a simple linear function as the basis for its entropy measure. The entropy measure is then used as a cost function for the selection of the optimal image threshold.

FRAT is part of a critical NASA system used to identify and track foreign object debris (FOD) during Space Shuttle liftoffs. FRAT is also a key analysis tool used in the current investigation into the Space Shuttle Columbia tragedy.

FRAT features include

- Exploitation of image pixel value histogram to avoid dealing with individual pixels
- Use of entropy measure as the criterion for selection of optimal threshold value
- Improvement on membership function to achieve more reliable and faster results

Commercial Opportunities

NASA is seeking companies to license this technology under its technology commercialization program, which seeks to stimulate commercial use of NASA-developed technologies. This technology is currently copyright protected, and a patent application is in process.

For More Information

If you would like more information about this technology or NASA's technology transfer program, please contact:

Kirsten Rieth		John Gedder
NASA Technology Applications Team		NASA Technology Applications Team
919.967.4991	Phone	919.941.8372
919.541.6221	Fax	919.941.8309
[illegible]	E-mail	[illegible]

RTI INTERNATIONAL

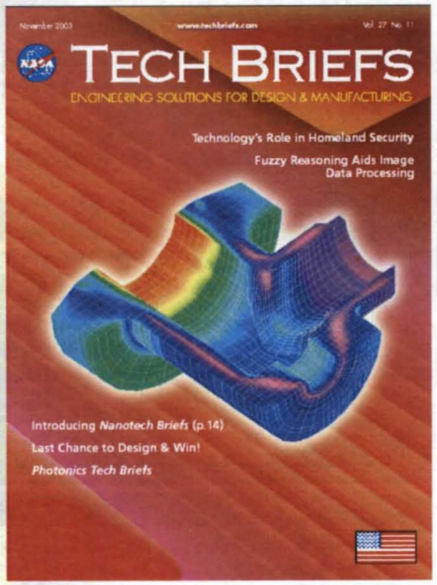
Catalog

Figure 9

Commercialization (Cont.)

ASRC Aerospace Corp.

Kennedy Space Center



Commercialization (Cont.)

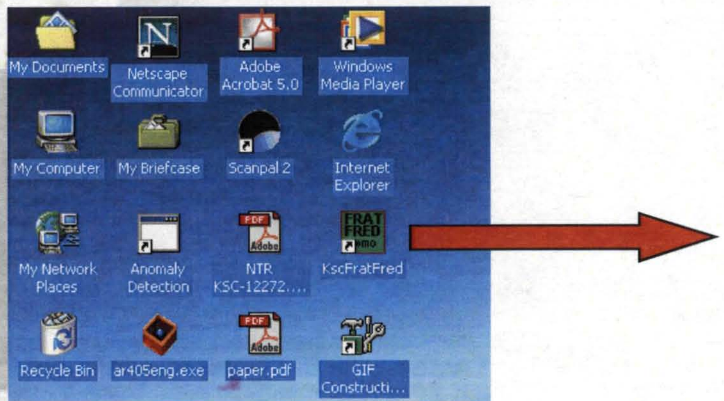
ASRC Aerospace Corp.

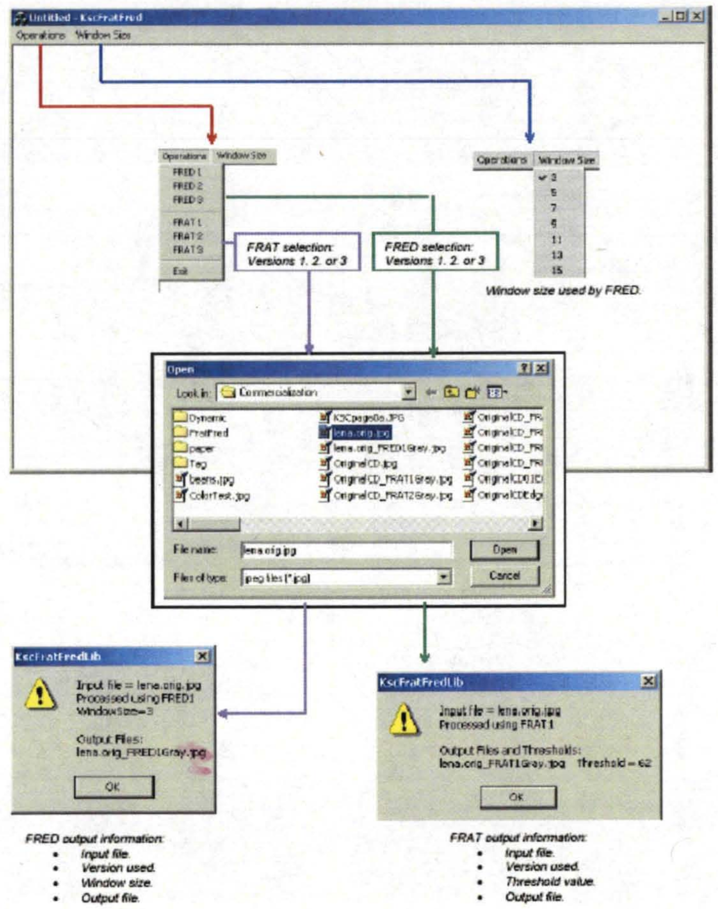
Kennedy Space Center

Commercialization (Cont.)

Kennedy Space Center

ASRC Aerospace Corp.





Commercialization: Status Summary

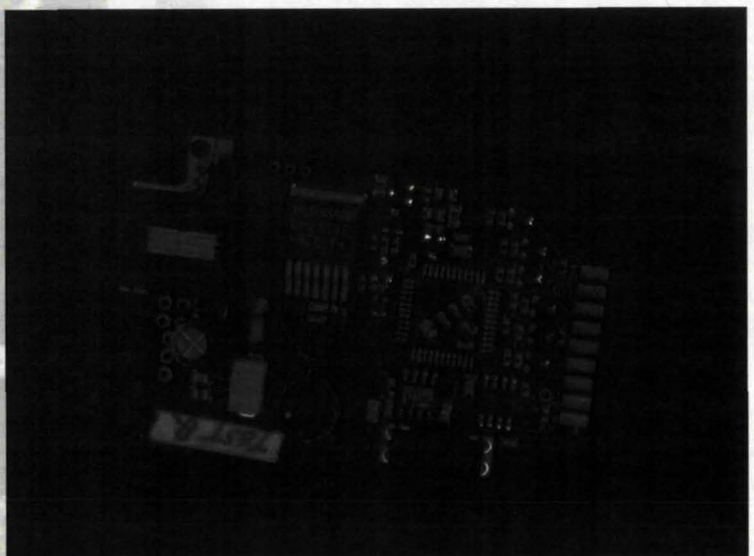
- *Patents already filed by NASA (February 2004).*
- *Marketing and Promotion already in place by RTI.*
- *2 Software Usage Agreements executed.*
- *2 License Agreements executed.*
- *3 License Agreements being executed.*
- *3 License Agreements in negotiation.*

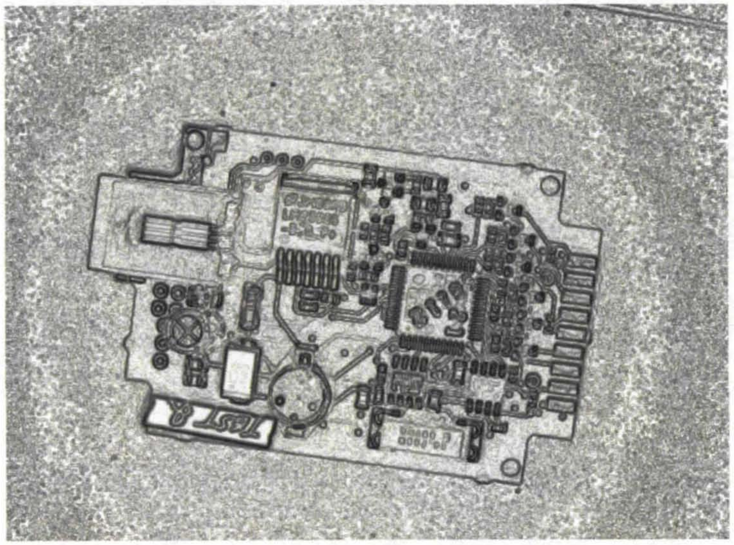
Commercialization: Selected Applications

ASRC Aerospace Corp.

Kennedy Space Center

Image enhancement

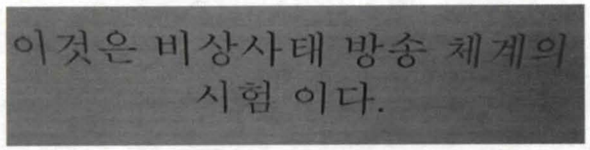




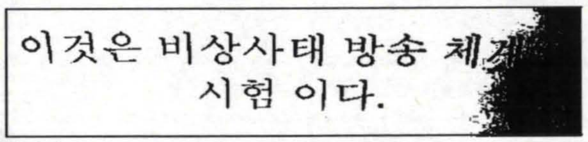
Commercialization: Selected Applications

ASRC Aerospace Corp.

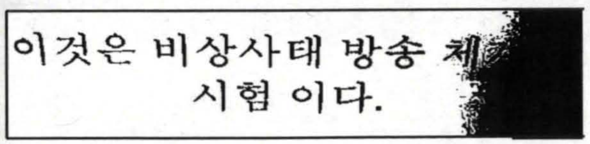
Kennedy Space Center



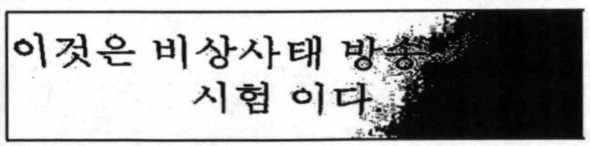
Original gray-scaled image



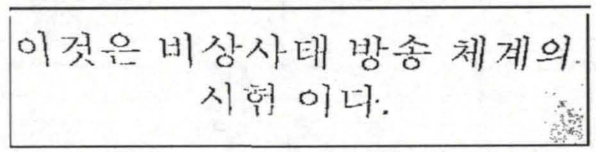
Binarization via FRAT.



Binarization via Otsu method.



Binarization via Huang-Wang method.



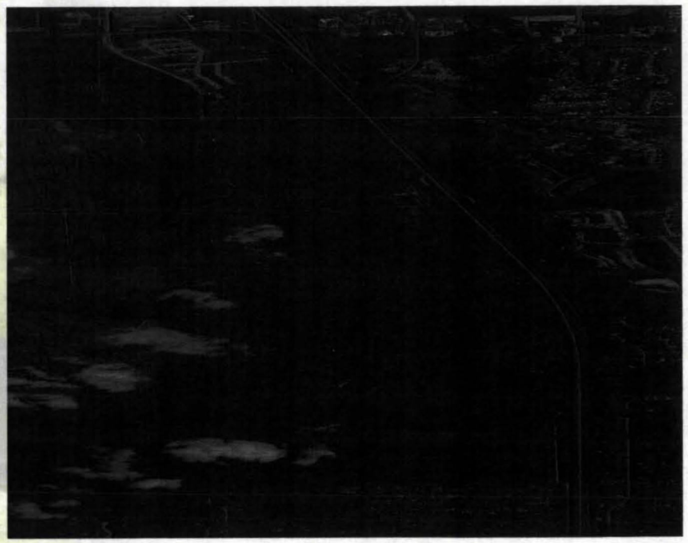
Enhancement prior Binarization
(via FRAT).

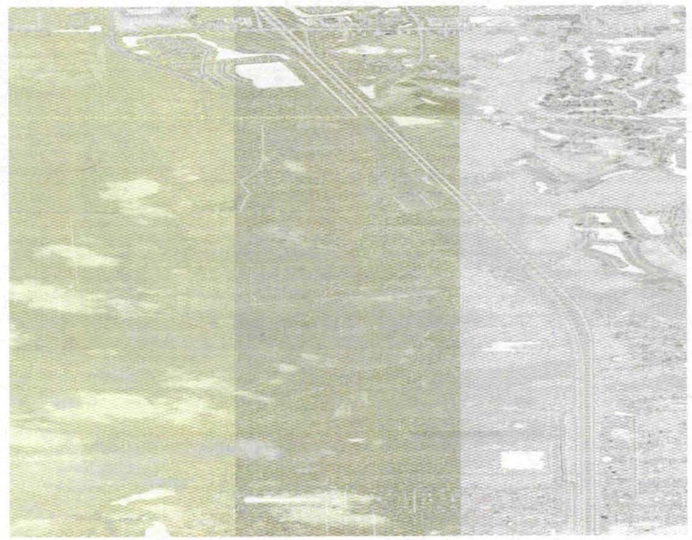
Commercialization: Selected Applications

ASRC Aerospace Corp.

Kennedy Space Center

Image enhancement





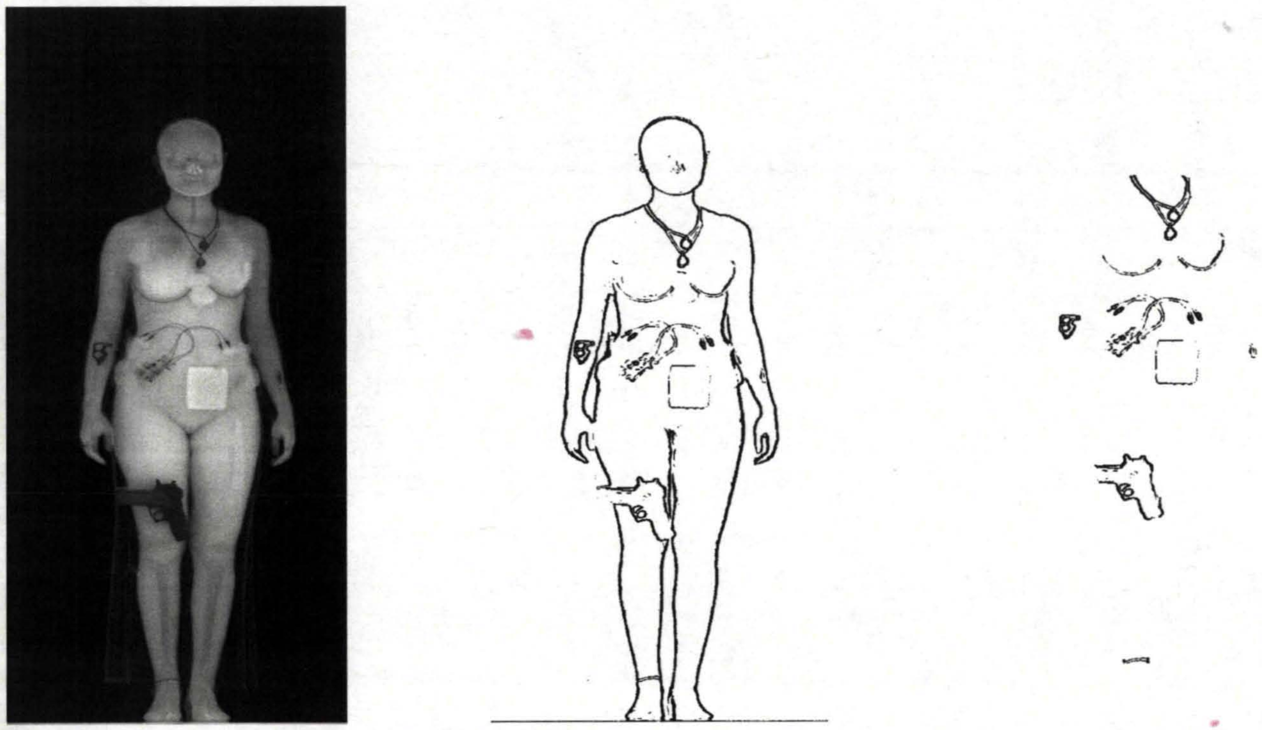
Commercialization: Selected Applications

ASRC Aerospace Corp.

Kennedy Space Center

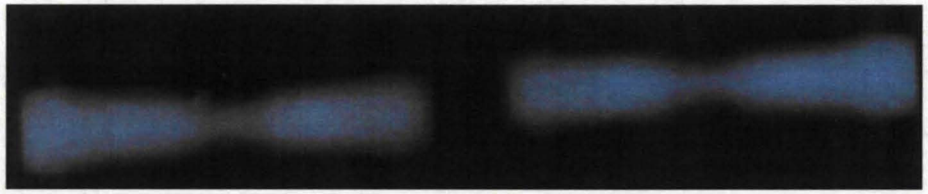
AS&E Inc.

Human Screening & Privacy Protection

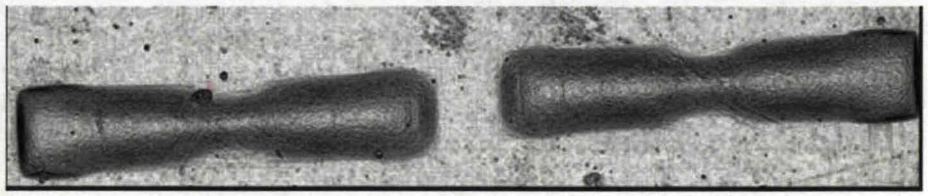


NASA JSC

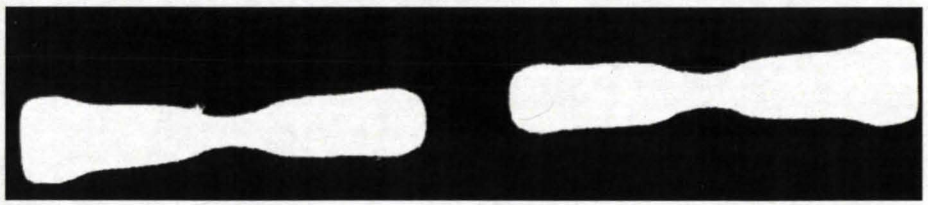
Visual inspection based on x-ray images



Original x-ray image of two pyrotechnic valves.



Enhancement via FRED



Segmentation via FRAT

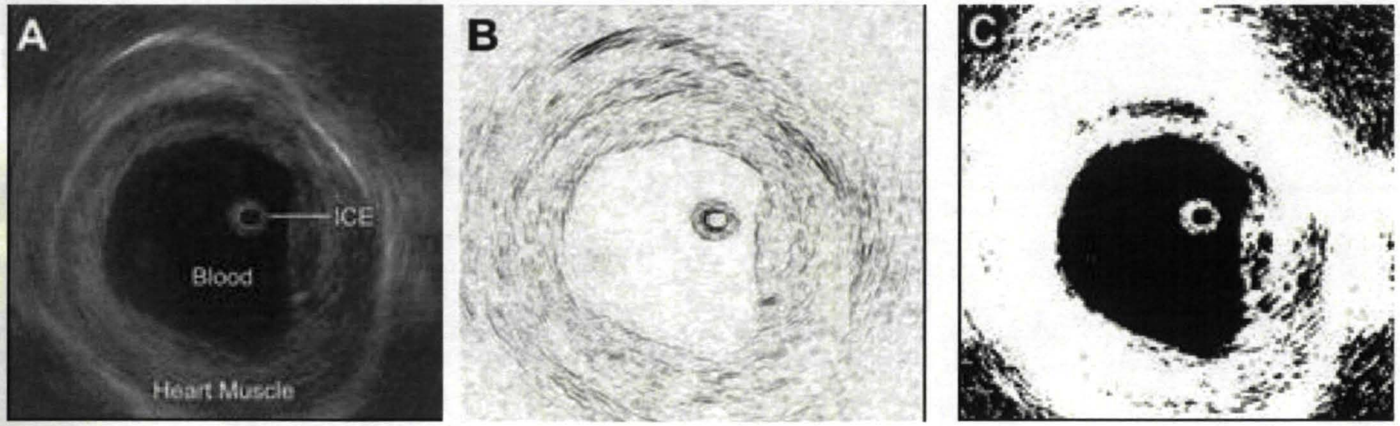
Commercialization: Selected Applications

ASRC Aerospace Corp.

Kennedy Space Center

Baylon School of Medicine

3D heart Visualization



Original image *FRED* *FRAT*

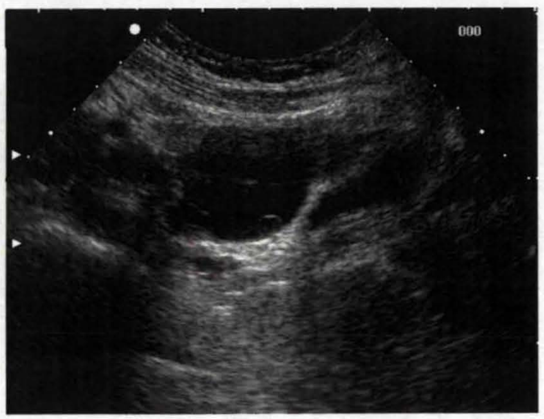
A. *Cross-sectional (tomographic) image of the left ventricular cavity of the dog heart acquired by an intracardiac echocardiography (ICE) catheter. Circle indicates ICE catheter. Dark region indicates blood-filled cavity, which is bounded by the interior surface of the heart (endocardium).* ***B.*** *Result of FRED demo when applied to the ICE image depicted in A.* ***C.*** *Result of FRAT demo when applied to the ICE image depicted in A.*

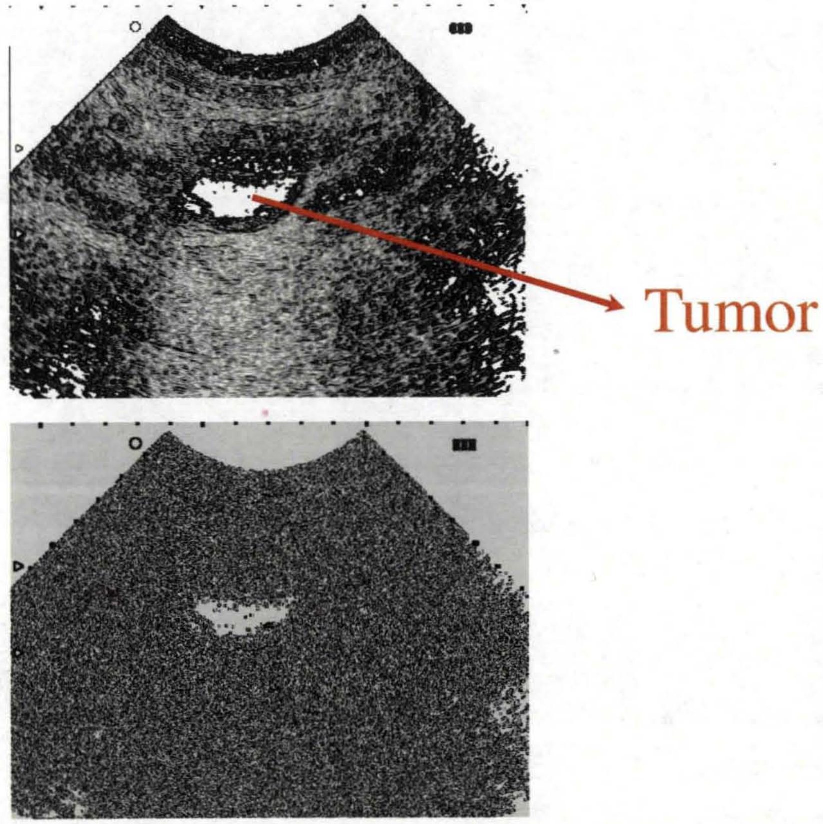
Commercialization: Selected Applications

ASRC Aerospace Corp.

Zeus Technologies, Inc.

Tumor detection on Sonograms





Commercialization: Selected Applications

ASRC Aerospace Corp.

Kennedy Space Center

Zeus Technologies, Inc.

X-ray image visualization enhancement